Muon Collaboration

Muon Collaboration R&D at Fermilab

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DOE Program Review. Fermilab, March 2004

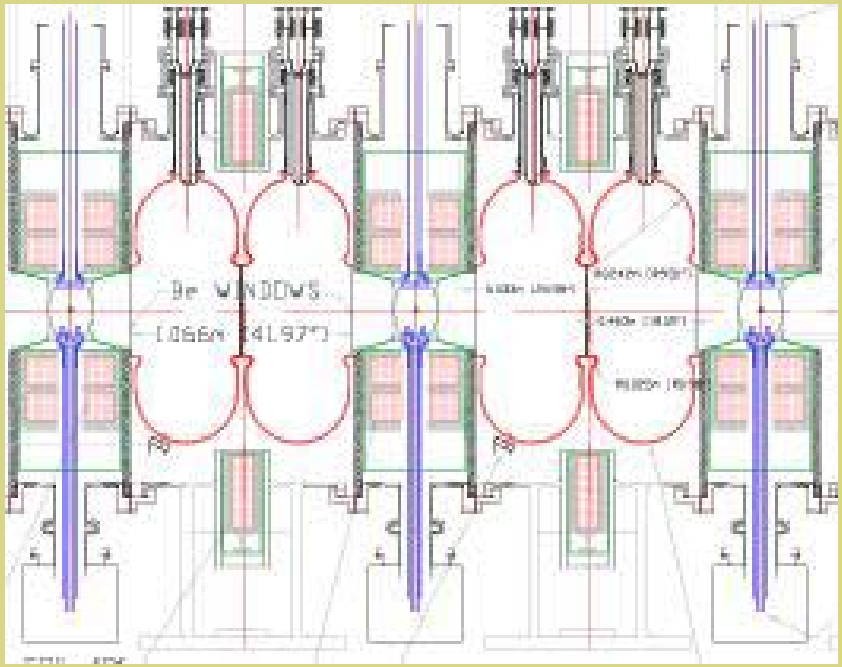
INTRODUCTION

1. Fermilab is one of the three lead-laboratories for the Neutrino Factory and Muon Collider Collaboration (Muon Collaboration).

2. Within the framework of the Muon Collaboration, Fermilab is host to the MUCOOL sub-activity, which is the R&D program to develop the technology required for a muon ionization cooling channel.

3. The Fermilab group also makes contributions central to the design & simulation studies focused on significantly reducing the cost of a neutrino factory.

MUCOOL R&D



70 Physicists from 16 Institutions

Mission: To prototype and test all the components needed for a muon ion-ization cooling channel.

High-gradient RF Cavities operating in a multi-Tesla magnetic field.

Liquid hydrogen absorbers with very thin windows, operating safely next to an RF cavity within a lattice of solenoids.

→ Engineering test of a short cooling section in a high-intensity beam at the 400 MeV Fermilab Linac.

External technical review (MUTAC) Report:

"Ionization cooling remains the primary R&D issue for the (muon) collab-oration. The most difficult part is the development and integration of the hardware, which is the goal of the MUCOOL efforts."

RF R&D

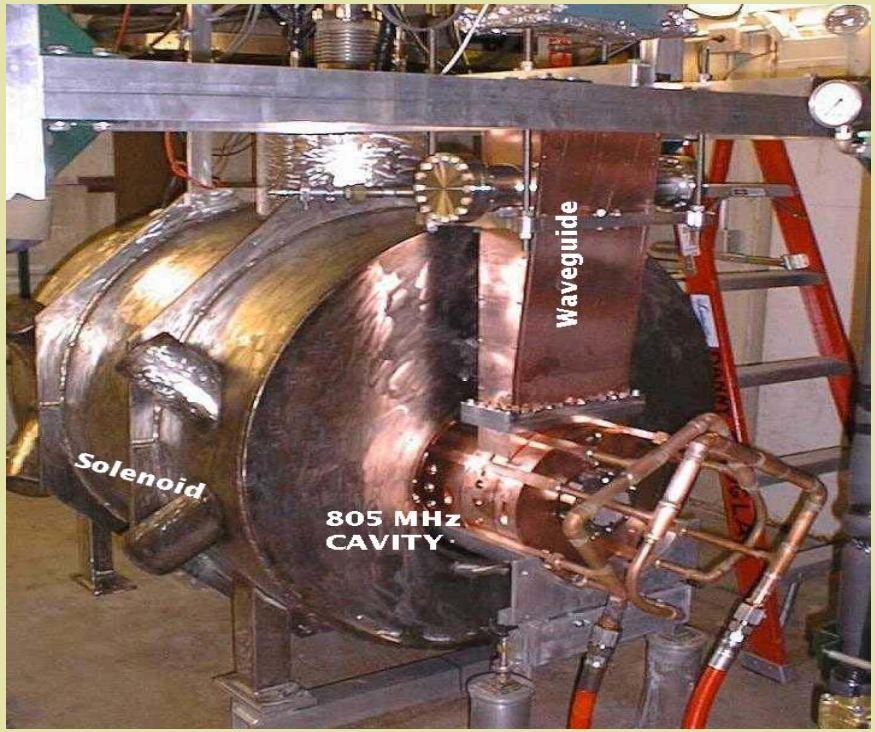
Need 201 MHz high gradient cavities to operate in multi-Tesla solenoid field which focuses the dark current electrons → high current densities

Would like to use a pillbox-type Cavity (at fixed peak power doubles gradient on-axis) using, for example thin Be foils to close the aperture:

→ Multipactoring ?

→ Cavity detuning due to RF heating ?

Initial R&D at 805 MHz → cheaper & faster



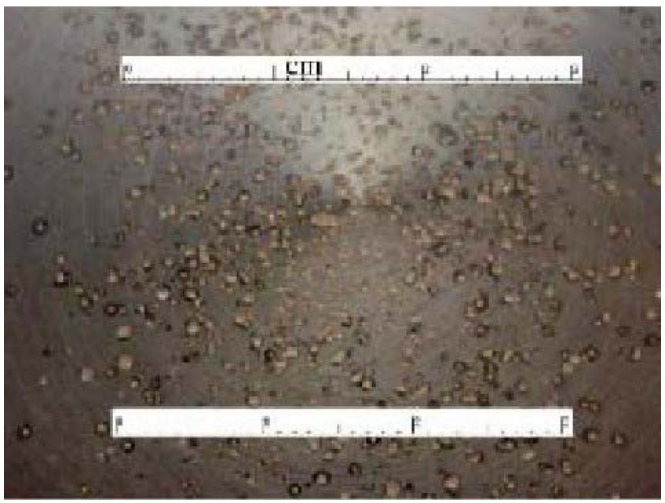
Lab G High Power 805 MHz Test Facility
12 MW klystron
Linac-type modulator & controls
X-Ray cavern
5T two-coil SC Solenoid
Dark-current & X-Ray instrumentation

805 MHz RF R&D Results - FY02/03

Window damage at high gradients in multi-Tesla field for open-cell cavity

Open cell cavity

805 MHz Cavity built & tested in magnetic field
→Surface fields 53 MV/m achieved
→Large dark currents observed
→Breakdown damage at highest gradients in 2T field
→Ph.D Thesis: Vincent Wu (U. Cincinnati)

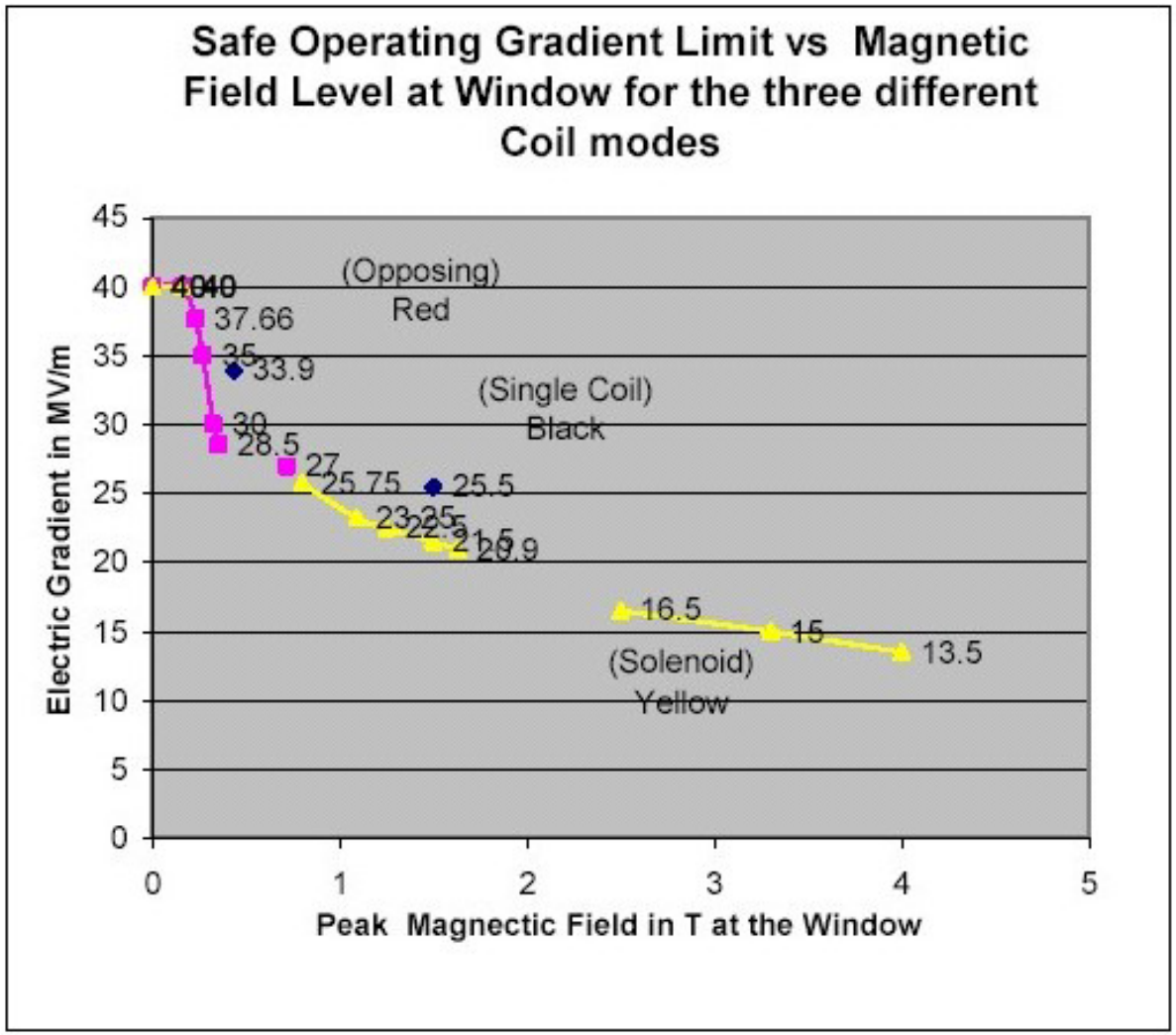


Window damage to Cu window for pillbox cavity

Pillbox cavity with thin conducting Windows

805 MHz single cell cavity tested in magnetic field
→Breakdown problems with Cu windows
→Be windows operated OK at 18 MV/m in 2T field
… but breakdown with higher magnetic fields.
→no serious multipactoring problems
→no serious cavity detuning due to RF heating of foil

805 MHz RF R&D Results – FY03/04



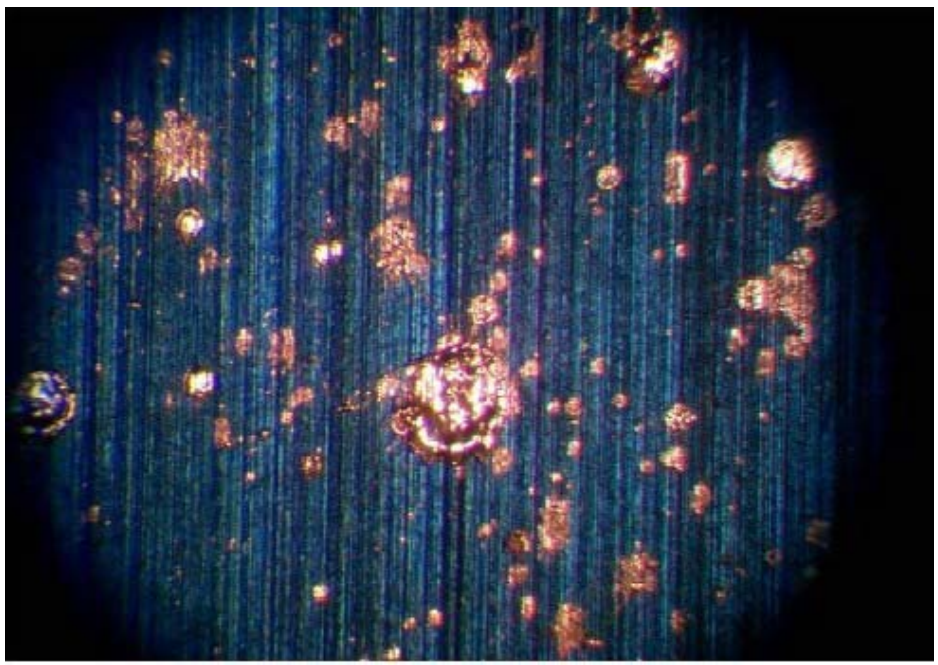
Maximum operating gradient determined for a variety of magnetic field configurations.

Results seem to lie approximately on a universal curve.

805 MHz RF R&D – FY03/04

Pillbox cavity reached 40 MV/m in Lab G with no magnetic field

Replaced copper windows with TiN coated Be windows and reconditioned cavity in magnetic field → NO WINDOW DAMAGE but sputtered Cu from cavity iris.



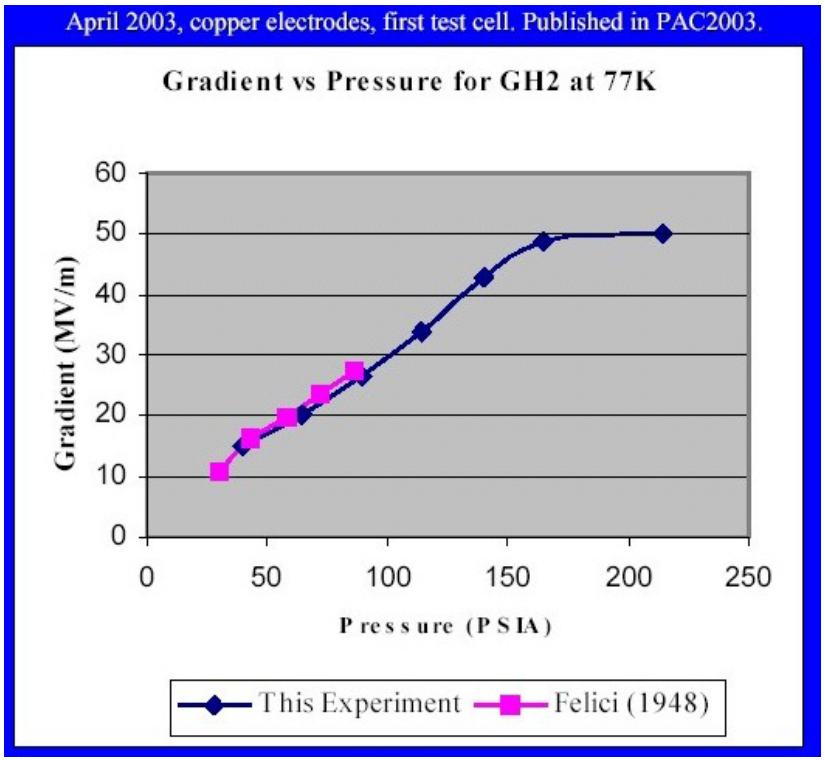
Results are encouraging.

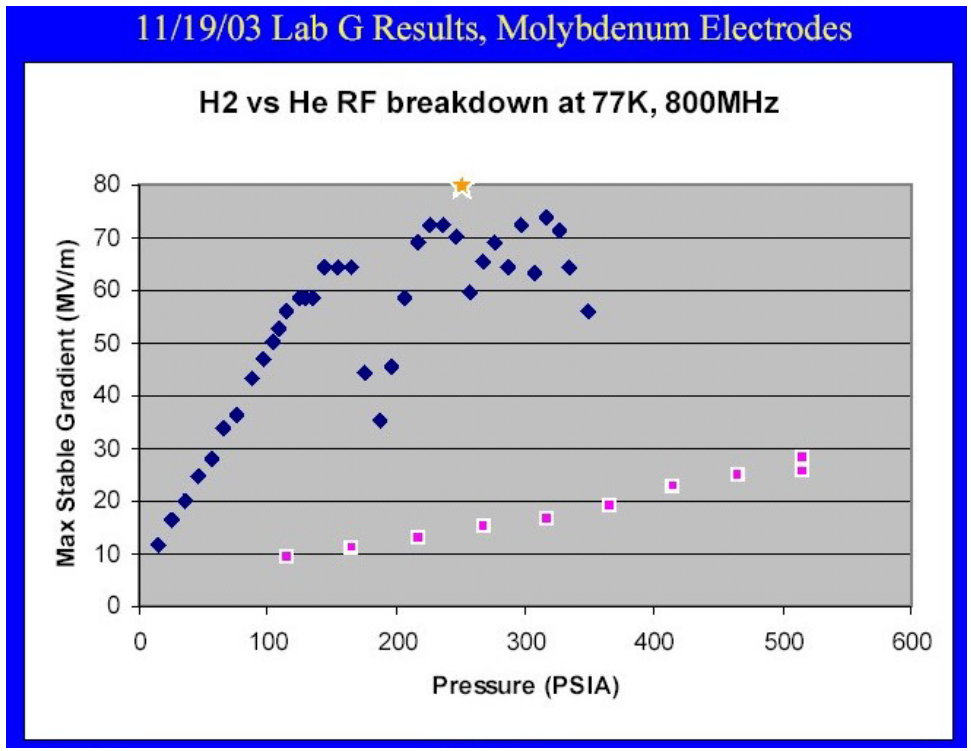
Next step is to explore coating the whole cavity
And perhaps try other cavity materials

805 MHz RF R&D – Muons Inc (R. Johnson et al)

Alternative cooling cell idea … rf channel filled with high pressure hydrogen gas.

High pressure test cells built and max rf gradient measured versus pressure → encouraging results.





RF Workshop

To expose our results to a wider audience, discuss other relevent results, and encourage some discussion, a Workshop on high-gradient rf limitations was held at ANL Oct 7-9 2003

(http://www.mice.iit.edu/rfworkshop/)

→ LOTS OF INTEREST

805 MHz RF R&D – Good News and Bad News

Unfortunately the recent 805 MHz klystron tube problems at the linac resulted in us donating the Lab G klystron for the common good .. So the Lab G program was prematurely terminated in January.

Fortunately we have a new test area, and we are being given support to re-establish our rf R&D program in the new area within the next couple of months (we hope).

Liquid Hydrogen Absorber R&D

Led by consortium of Illinois Universities (ICAR). Fermilabs main contributions: safety oversight, cryo design & help with window measurements.

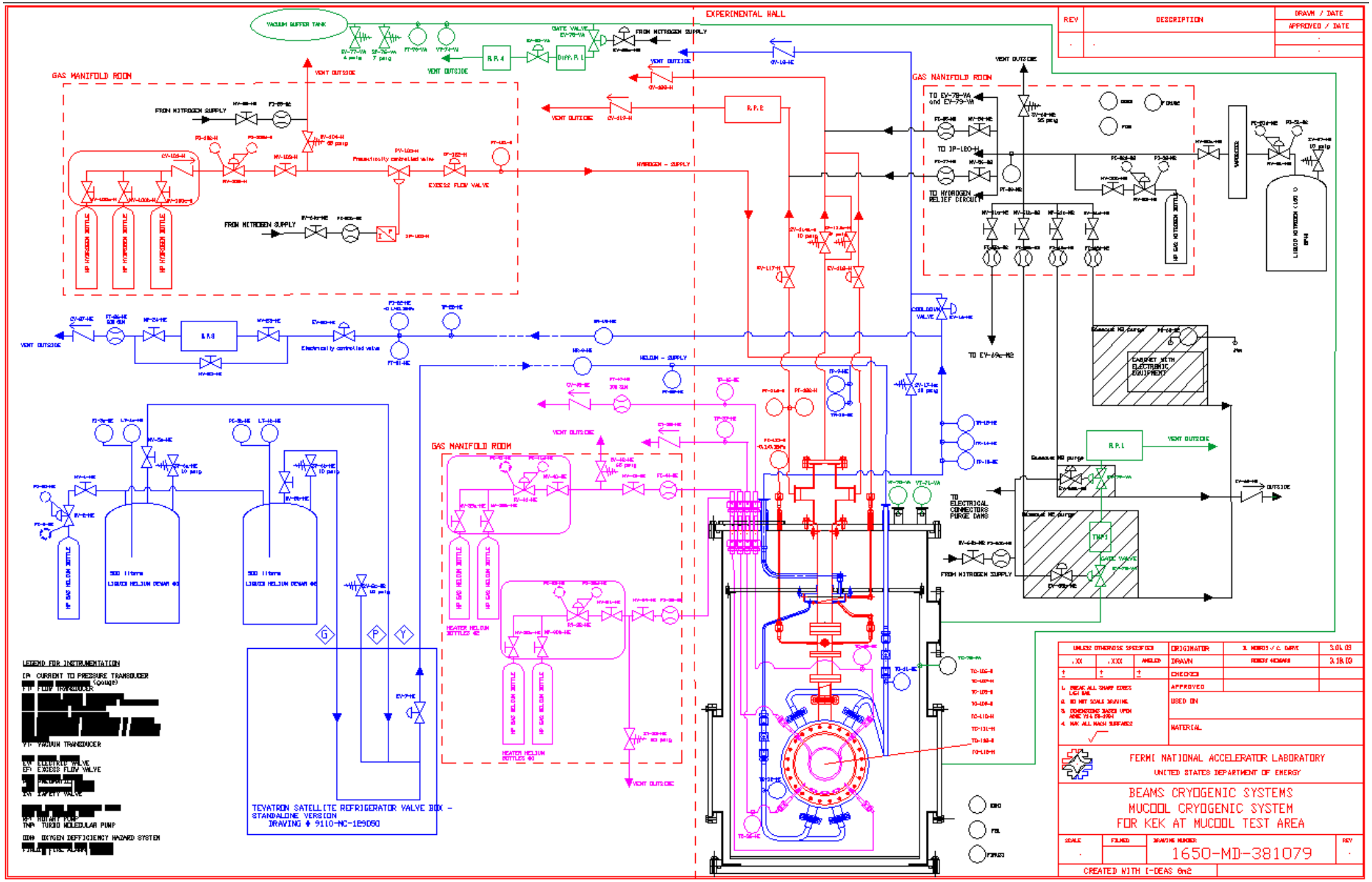
Main Challenges: → Very thin windows (to minimize scattering)
→ Heat removal (from DEDX Losses)
→ Engineering for Safety

Previous years: → Very thin windows successfully designed, built, & tested.
→ Two absorber concepts developed (forced flow & convection).
→ Convection absorber prototype built by KEK Collaborators

This Year the focus is on filling the first Liquid Hydrogen Absorber Prototype.

Preparing to Fill the First LH Absorber – Status Now

Preparing to Fill the First Liquid Hydrogen Absorber



Preparing to Fill the First LH Absorber – Test List

(1) L-Ne(28-30K) Test at KEK

Absorber & H2 Pipes; He leak test at R.T. and 80K; $< 1 \times 10^{-9}$ atm.cc/sec
Absorber & H2 Pipes; 13 hours at 1.0-2.0 bar, 28-30K -- OK (0.9-1.2 x 10^{-7} Torr)

(2) Pressure Test at Room Temperature (MAWP is 1.7 bar)

Absorber & H2 Pipes; 60min at 2.0 bar -- OK
He channel ; 60 min at 2.0 bar -- OK

(3) Helium Leak Test at Room Temperature

Absorber & H2 Pipes; $< 1 \times 10^{-9}$ atm.cc/sec *
He channel; $< 1 \times 10^{-9}$ atm.cc/sec *

(4) Pressure Test at 80K (LN2 flow in He Channel)

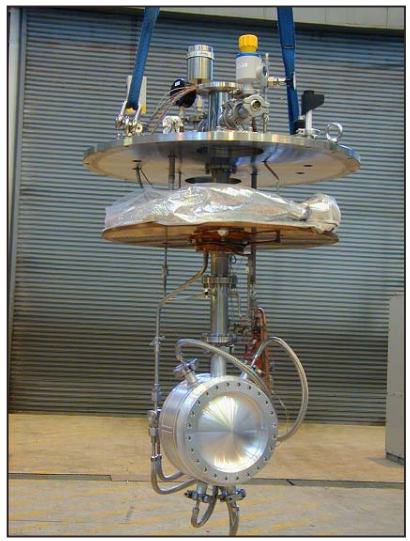
Absorber & H2 Pipes; 30 min at 2.5 bar -- OK

(5) Helium Leak Test at 80K

Absorber & H2 Pipes; $< 1 \times 10^{-9}$ atm.cc/sec *

(6) Vacuum Vessel Pressure Test at Room Temperature

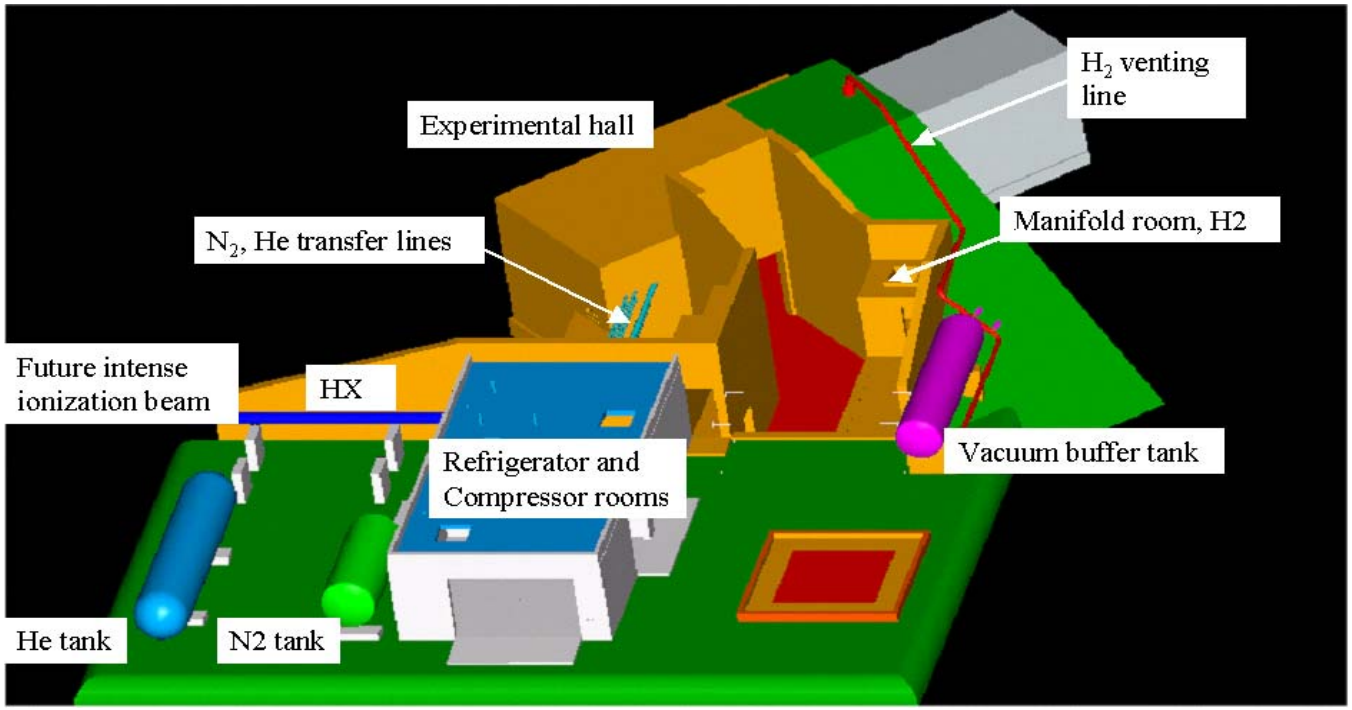
Vacuum Vessel; 68 min at 2.5 bar -- OK



Absorber II
KEK FNAL

(2)-(6) were tested on FNAL/US safety regulations at FNAL.

* Calibrated sensitivity < 10^{-9} , B.G.=1.3~4.4 x 10^{-9} atm.cc/sec



MUCOOL Test Area at the end of the Linac

- Fill Liq. H absorbers: U.S. & Japanese prototypes
- High-Power tests of 201 MHz & 805 MHz Cavities
- Engineering test: Absorber–Cavity–Solenoid system
- Development of new beam diagnostics
- Eventual engineering test in high-intensity beam

Test Program

MUCOOL Test Area Last Year

Status last year

MUCOOL Test Area COMPLETED in FY03 on time, on budget, and with no accidents

Neutrino Factory Design Work

Fermilab has a small but active group working on developing and simulating Neutrino Factory designs.

Present effort is on updating the Muon Collaboration baseline design for the ongoing APS sponsored Neutrino Study. This is the first step towards "Study III" in ~ 2 years time.

Focus is on cost reduction … and there is some significant progress based on ideas from the Fermilab group: New phase rotation scheme (D. Neuffer) & non-scaling FFAG (C. Johnstone et al).

Also work on ring coolers (V. Balbekov) … but we now think this is likely to beof more relevance to Muon Colliders than Neutrino Factories. With the larger acceptance of the FFAG (c.f. an RLA) a shorter, simpler, and more cost effective linear cooling channel can be used.

Cost Reduction Design Work : Phase Rotation & Bunching

Phase Rotation:

Induction Linac replaced with NCRF system with multiple frequencies.

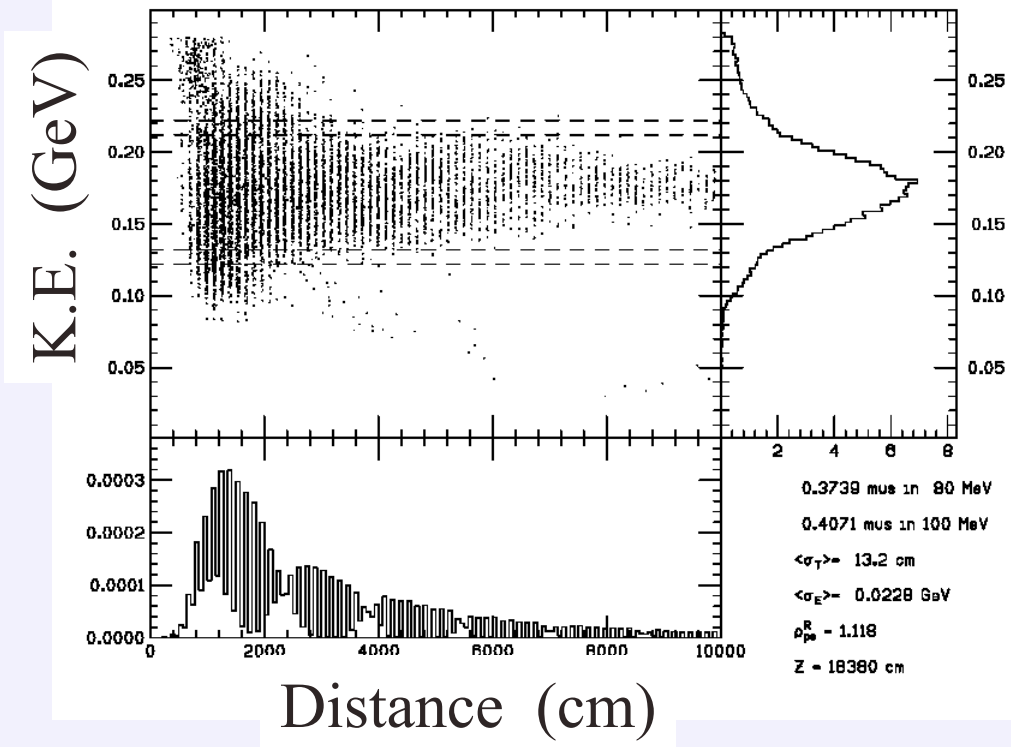
Idea: D. Neuffer (FNAL)

New Ph.D Student:
Alexey Poklonskiy (MSU)

→ Cheaper Technology
→ Shorter Length
→ Better Performance

	Study II	NOW	FACTOR
Total Length (m)	328	166	0.51
Acc. Length (m)	269	35	0.13
Acc. Type	Ind. LINAC	NCRF	

Bunch Train After Phase Rotation



Cost Reduction Design Work : Acceleration

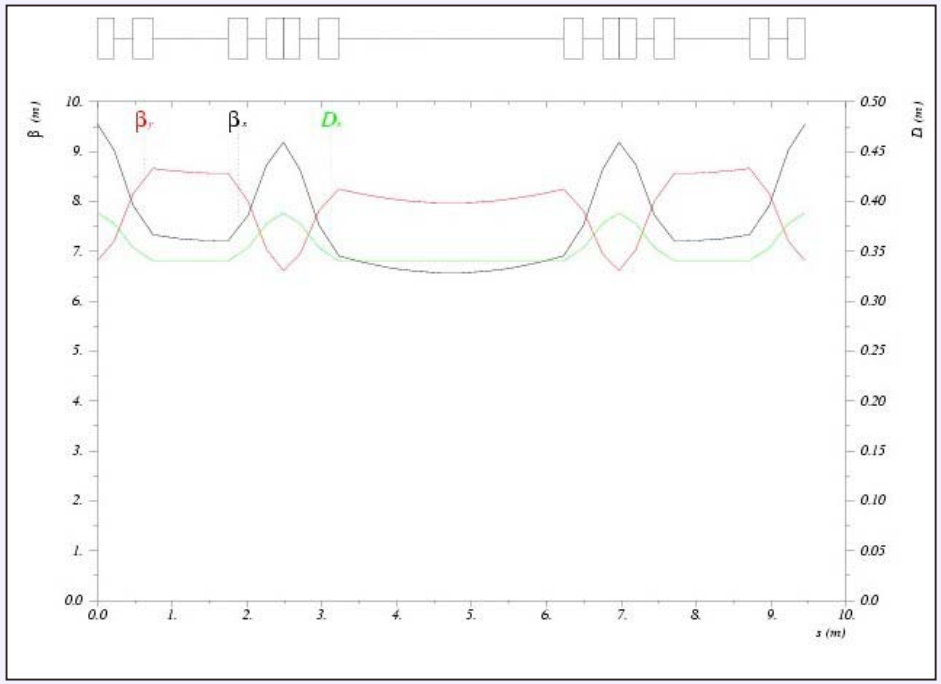
Acceleration:

RLA replaced with a new type of FFAG accelerator ("non-scaling FFAG")

	Study II	NOW	FACTOR
Vac Length (m)	3261	730	0.22
Turn Length (m)	1494	730	0.49
Acc. Length (m)	288	102	0.35
Acc. Grad. (MV/m)	16	8	0.50

Idea: C. Johnstone (FNAL)

→ Single Arcs (vs. 4 in RLA)
→ Less RF



SUMMARY – Main Accomplishments in the last year

1. MUCOOL Test Area completed on time, on budget, no accidents.
2. Pillbox cavity tested at Lab G with Be windows. High gradient achieved with fields up to 2 Tesla with Be windows, no multipactoring or serious detuning issues encountered.
3. High-pressure hydrogen cavity measurements made (Muons Inc) and results are promising.
4. Preparations to fill the first Liquid hydrogen absorber prototype are advanced.
5. New ideas from the FNAL group for phase rotation and acceleration are becoming the new Neutrino Factory baseline for the ongoing APS sponsored Neutrino Study - may well lead to a significantly more cost effective neutrino factory design.

Future Plans

FY04
Equip MUCOOL Test Area
Design 400 MeV beamline to MTA
Fill first absorber with Liq. H2
Continue preparation for Feasibility Study III
FY05
201 MHz High Power Tests
Fill absorber next to operating cavity
Prepare 400 MeV beam capability
Initiate Feasibility Study III (cost effective design)
FY06 and Beyond
Complete Feasibility Study III
Cooling component engineering tests with Linac beam
Production of components for the MICE experiment